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Impacts of lead/zinc mining and smelting on the environment and human health in China

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Abstract Mining and smelting are important economic activities. However, mining-related industries are also some of the largest sources of environmental pollution from heavy metals. China is one of the largest producers and consumers of lead and zinc in the world. A large amount of lead, zinc, and related elements, such as cadmium, have been released into the environment due to mineral processing activities and have impacted water resources, soils, vegetables, and crops. In some areas, this pollution is hazardous to human health. This article reviews studies published in the past 10 years (2000–2009), on the environmental and human health consequences of lead/zinc mineral exploitation in China. Polluted areas are concentrated in the following areas: the junction of Yunnan, Guizhou and Sichuan provinces, west-central Hunan province, central Guangxi province, northern Guangdong, northwestern Henan province, the border between Shanxi and Gansu provinces, and the region of Liaoning province near Bohai. Lead (Pb) and cadmium (Cd) are the main pollutants and are associated with human health effects such as high lead blood levels in children, arthralgia, osteomalacia, and excessive cadmium in urine.

Keywords Lead/zinc mineral exploitation · Impact · Environment · Human health · China

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Introduction

The progress of human civilization has been driven by revolutions in the exploitation of mineral resources. The discoveries of copper and iron and the development of smelting technology led to the development of agriculture; the intensive exploitation of coal, oil and non-ferrous metals facilitated the development of industry; and the applications of uranium and silicon promoted the development of contemporary technology. But despite the importance of mineral resources for human progress, mineral extraction has caused serious environmental problems, especially heavy metal pollution (Moore and Luoma 1990; Rybicka 1996; Chopin and Alloway 2007).

Lead/zinc mining and smelting activities are some of the primary sources of heavy metals pollution in the environment (Horvath and Gruiz 1996; Yang et al. 2003; Li et al. 2007a). According to a global inventory of trace element emissions (Nriagu and Pacyna 1988), about 357 to 857 $\times$ 10^6 kg/year lead and 462 to 1,380 $\times$ 10^6 kg/year zinc are released into the environment by mining and smelting activities. Globally, lead ore processing is estimated to have released about 300 million tons of lead into the environment over the past five millennia, mostly within the past 500 years (Tong et al. 2000). From the eighteenth to the twentieth century, industrialization and intensive mining in European and American countries caused serious environmental pollution. In the resource-rich areas of England and Wales as well as the upper Mississippi river (near Iowa, Wisconsin, and Missouri), lead and zinc mining resulted in major heavy metal pollution of soil, water and sediments[1]. Some pollutants (lead, cadmium, zinc, copper) still persist in the environment, and many have migrated into other environmental media (Davis 1987; Holmgren et al. 1993; Besser et al. 2007). Heavily polluted soils and water bodies near the lead/zinc mines in Sartinia, Italy and S. Domigos, Portugal, have affected the health of local residents through the food chain (Leita et al. 1991; Pereira et al. 2004). Moreover, large quantities of tailings and waste rocks damaged the environment and human health in Aberfan (Wales, 1966), Stava (Italy, 1985), Aznalcóllar (Spain 1998), Baia Mare and Baia Borsa (Romania, 2000)[2].

Under certain conditions, heavy metals released by lead/zinc mining may activate, migrate and accumulate in various target media that may directly or indirectly impact plants, animals and humans (Wang et al. 1994; Chiaradia et al. 1997; Grattan et al. 2002; Liu et al. 2005a, b; Pusapukdepob et al. 2009; Bai and Yan 2008; Kim et al. 2008). Lead is not an essential element for the human body, and excessive intake can damage the nervous, skeletal, circulatory, enzymatic, endocrine, and immune systems. Children, pregnant women, and elderly people are particularly sensitive to lead exposure, and lead also has significant effects on intelligence quotients and physical development in children. Since the 1980s, when the United States and other developed countries began banning the use of lead in gasoline, welding, electronics and other products, lead releases (lead flux) and mean blood lead levels have been decreasing dramatically (Chillrud et al. 1999; Pirkle et al. 1994, 1998; Storch and Hagner 2004; Jones et al. 2009). However, lead-related health problems in China remain serious and require more attention (Bian 2008; Zhong and Zhang 2008).

Unlike lead, zinc is an essential element for the human body. It is an essential component of various enzymes and zymoexcitators and supports growth, tissue regeneration and the immune system. Nevertheless, excessive zinc intake can cause stomach cramps, nausea, and vomiting; high-dose, long-term Zn exposure can affect cholesterol balance, diminish immune system function, and even cause infertility[3].

Production from China's rich lead/zinc deposits has been increasing annually (Xi 2009). Many studies on Chinese lead/zinc mining and smelting activities have emphasized reserves and production from the perspective of resource utilization (Xue and Wang 2005; Cao 2006; Hu and Niu 2006; Wu 2008a, b). In this paper, we review and analyze the environmental pollution and human health effects, in the past 10 years (2000–2009), caused directly or indirectly by lead/zinc mineral industries in China. We present comprehensive data on pollutant characteristics, major pollutant types and symptoms of exposure in order to facilitate prevention, control, and elimination of the environmental and health risks associated with lead/zinc mining. This information is valuable for informing the government and public about existing problems and motivating them to move forward on reducing the adverse impacts.

[1] http://publications.environment-agency.gov.uk/pdf/SCHO1108BOZD-e-e.pdf

[2] http://ec.europa.eu/environment/waste/mining/index.htm

[3] http://www.atsdr.cdc.gov/tfacts60.html

Data and methods

Data used in this study includes publicly published articles and journal papers. Arc Info was used for mapping.

Results: environmental and human health effects

Most lead/zinc deposits in China are primarily composed of sulfide minerals. Upon release into the environment, galena, sphalerite and related sulfides oxidize, decompose and release H^+, SO_4^{2-} and metals. Mobile Pb, Zn, Cd and other metals then move into adjacent water bodies, soils, and plants, where they directly or indirectly threaten human health (Wu et al. 2001; Ye et al. 2006; Kovacs et al. 2006; Rodriguez et al. 2009).

Water pollution

Water bodies close to lead/zinc mining industries have a high risk of pollution from wastewater associated with mining (ore-dressing) and smelting. Research (Table 1) indicates that concentrations of heavy metals in polluted water bodies mostly exceed water quality criteria V according to national standards (GB 3838-2002 China; Table 2). The major pollutants are Pb, Zn, and Cd. Most pollutants are stored in or absorbed into sediments, which may act as a secondary source of environmental pollution. As shown in Fig. 1, water pollution is most severe in central Guangxi province, the junction of Yunnan, Guizhou and Sichuan provinces, central Hunan province, northern Guangdong province and northern of Liaoning province.

Table 1 Water pollution associated with lead–zinc mining and smelting activities in China

Time	Place	Pollution source	Media type	Pollutants	Reference
2001	Hezhang, Guizhou	Mining and smelting	River water and sediment	Pb, Zn, Cd and Cu	Wu et al. 2001
2002; 2003	Liupanshui, Guizhou	Mining	River water and sediment	Pb and Zn	Zhang et al. 2004, Zhang 2005
2003	Hezhang, Guizhou	Smelting	River water	Pb and Zn	Zhang et al. 2004
2005	Hezhang, Guizhou	Smelting	Lake sediment	Pb, Zn and Cd	Bi et al. 2006
2005	Fenghuang, Hunan	Mining	River water	Pb and Hg	Li et al. 2007a
2005	Tieling, Liaoning	Mining	River water and sediment	Cd, Pb, Zn and Ca	Ma et al. 2007
2005	Dexing, Jianxi	Mining	River water	Pb, Zn and SO_4^{2-}	Zeng et al. 2007
2007	Huludao, Liaoning	Smelting	River sediment	Pb, Cd and Zn	Zheng et al. 2007a
2007	Lechang, Guangdong	Mining	River water and sediment	Pb, Cd, Cu and Zn	Yang et al. 2007a
2007	Lanping, Yunnan	Mining	Grounder river and water	Pb and Cd	Li et al. 2007b; Wang et al. 2009a
2008	Duyun, Guizhou	Mining	River water and sediment	Pb, Cd, etc.	Pan et al. 2008
2009	Hunan	Mining and smelting	Xiangjiang river	Heavy metals form mining and smelting	China Economic Weekly 2009, 16
2009	Shaoguan, Guangdong	Mining	River water	Pb, Cd, Zn, etc.	Southern Metropolis Daily 2009-7-22

Table 2 Environmental quality standards for surface water in China of GB 3838-2002

Item/ elements	Quality standard for each criteria[a] /unit mg/L				
	I	II	III	IV	V
Pb	0.01	0.01	0.05	0.05	0.1
Zn	0.05	1.0	1.0	2.0	2.0
Cd	0.001	0.005	0.005	0.005	0.01
Cu	0.01	1.0	1.0	1.0	1.0
Hg	0.00005	0.00005	0.0001	0.001	0.001

[a] *I* mainly applicable to national nature reserves and water sources, *II* mainly applicable to sources of centralized drinking surface water—primary conservation areas, *III* mainly applicable to sources of centralized drinking surface water—second level conservation areas, *IV* mainly applicable to water spaces for general industry and entertainment of indirect physical contact, *V* mainly applicable to water spaces for agriculture and general landscape

Soil pollution

Soil is easily polluted by lead/zinc mining and smelting activities (Kachenko and Singh 2006; Liao et al. 2008). Research (Table 3) has demonstrated that soils and plants adjacent to mining areas are heavily polluted with Pb, Cd and, to a lesser extent, Zn and Cu. Concentrations of heavy metals in polluted soils mostly exceed soil quality criteria III according national standards (GB 19618-1995 China; Table 4), and those polluted lands are no longer appropriate for agricultural production. Compared to natural soils, polluted soils have fewer nutrients and reduced microbial diversity, which inhibits plant growth. Limestone-derived soils in southwestern areas of China such as Guizhou and Guangxi are alkaline, rich in calcium and basic (high pH) and therefore limit the mobility of heavy metals to some degree. Nevertheless, these soils are toxic due to their high concentrations of heavy metals. Soil pollution due to lead/zinc exploitation is more widely distributed and more severely impacted than water pollution (Fig. 2).

Crop pollution

Crops growing near lead/zinc mineral industries appear to accumulate Cd, Pb, and Zn. These crops are exposed to pollutants through air deposition, wastewater irrigation, and soil pollution. Rice in lead/zinc mining areas accumulates significant levels of Cd, and vegetables accumulate Cd and Pb. Pollution accumulates most in leaf vegetables, followed by bulb vegetables and root vegetables.

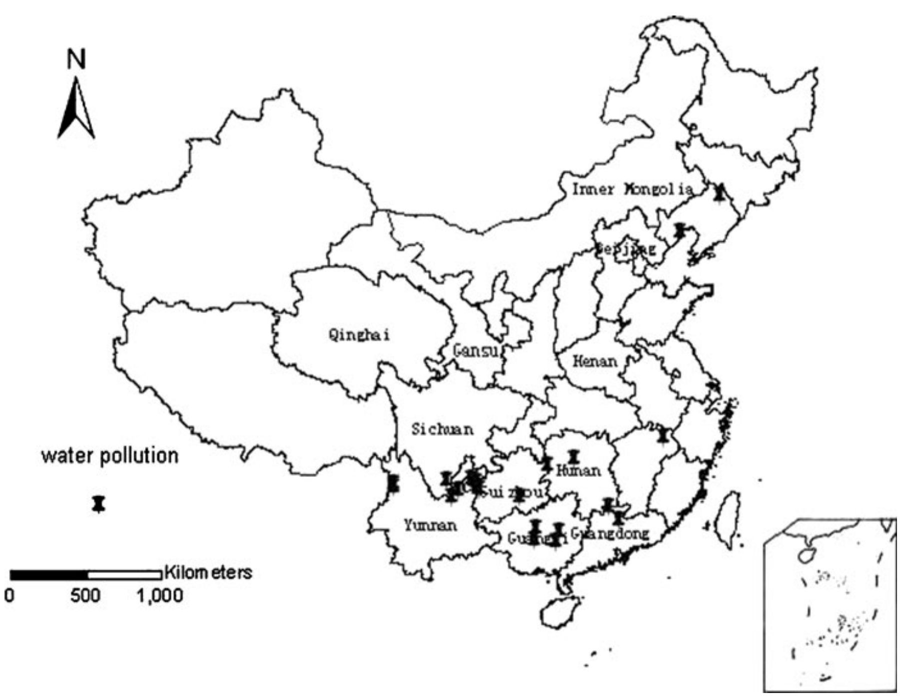

Fig. 1 Diagram of water pollution due to lead–zinc mining and smelting in China

Table 3 Soil pollution due to lead–zinc mining and smelting activities in China

Time	Place	Pollution source	Media type	Pollutants	Reference
2001	Yongzhou, Hunan	Ore-dressing	Soils	Cd, Pb, Cu and Zn	Peng et al. 2007
2002	Fengcheng, Liaoning	Mining	Peripheral soils	Cd, Pb, Zn and Cu	Gu et al. 2005
2003	Shuicheng and Hezhang, Guizhou	Mining and smelting	Peripheral soils	Pb, Zn and Cd	Yang et al. 2003
2004	Duyun, Guizhou	Mining	Soils	Cd and Zn	Ye et al. 2004
2005	Shaoxing, Zhejaing	Ore-dressing	Peripheral soils	Pb, Cd, Zn and Cu	Li et al. 2005
2006	Shuicheng, Guizhou	Smelting	Soils	Cd	Chen 2006
2006	Quzhou, Zhejiang	Mining	Peripheral soils	Pb, Zn, Cd and Cu	Zhang et al. 2006
2006–2007	Hanyuan, Sichuan	Mining	Soils	Cd, Zn and Pb	Hou 2006; Feng 2006
2007	Huludao, Liaoning	Smelting	Soils around plant	Cd, Pb, Zn and Cu	Zheng et al. 2007b
2007	Duyun, Guizhou	Ore-dressing	Soils	Pb	Mao and Yu 2007
2007	Linxiang, Hunan	Ore-dressing	Soils to tailings	Pb and Cd	Guo et al. 2007
2007	Zhuzhou, Hunan	Smelting	Soils	Cd, Pb, Zn, Hg and Cu	Wu 2007; Dong 2007
2008	Siding, Guangxi	Mining and smelting	Soils	Pb and Zn	Yin et al. 2008
2008	Fengxian, Shanxi	Smelting	Soils around plant	Zn, Pb, Cd and Cu	Wang and Zhu 2008
2008	Chenzhou, Hunan	Mining	Soils	Cd, Pb, Zn and Cu	Tao 2008
2008	Fujian	Mining and smelting	Soils near mining area	Cd, Pb, Zn and Mn	Wang et al. 2010
2009	Guangxi	Mining	Paddy soils	Cd, Pb, Zn and Cu	Deng et al. 2009
2009	Nanjing, Jiangsu	Mining	Soils of mining area	Pb and Cd	Zhu 2009
2009	Hanyuan, Sichuan	Mining	Soils	Pb and Cd	Wang et al. 2009b
2009	Changning, Hunan	Mining	Farm soils	Cd, Pb, Zn and As	Wei et al. 2009
2009	Weining, Guizhou	Mining and smelting	Peripheral soils	Cd, Pb and Zn	Wu et al. 2009
2009	Huize, Yunnan	Smelting	Soils close to plant	Cd, Pb and Zn	Fang and Cao 2009

Table 4 Environmental quality standards for soil in China of GB 19618-1995

	Quality standard for each criteri [a]/unit mg/kg				
	I	II			III
		pH < 6.5	pH < 6.5	6.5~7.5	pH > 7.5
Pb ≤	35	250	300	350	500
Zn ≤	100	200	250	300	500
Cd ≤	0.20	0.30	0.30	0.60	1.0
Cu ≤	35	50	100	100	400
Hg ≤	0.15	0.30	0.50	1.0	1.5

[a] *I* mainly applicable to national nature background of soil quality limit value, *II* mainly applicable to protect agricultural production and maintain the human health of the soil quality limit value, *III* mainly applicable to the soil quality limit value for the plant normal growth of agro-forestry production

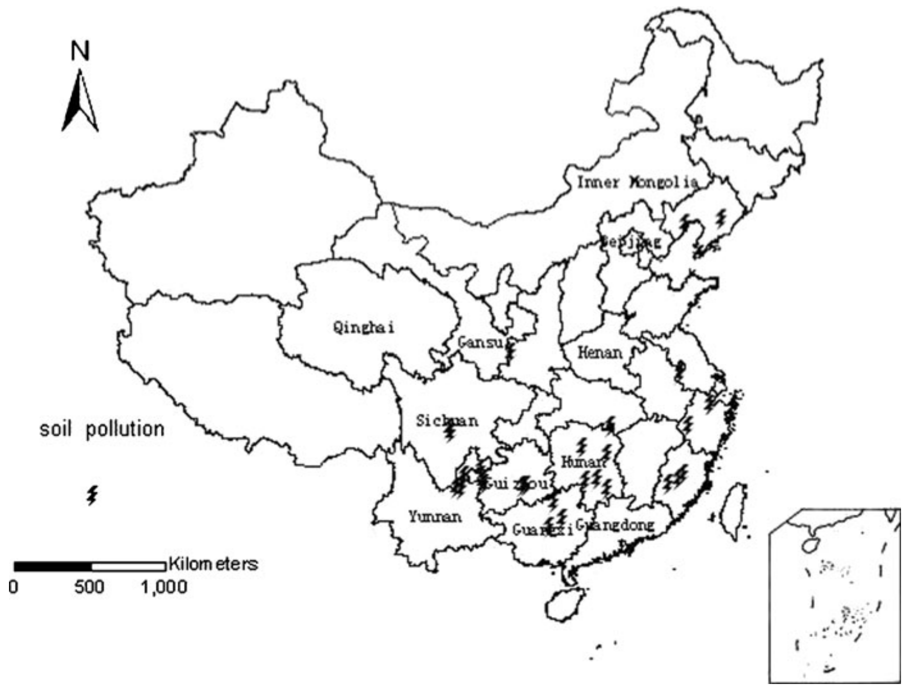

Fig. 2 Diagram of soil pollution due to lead–zinc mining and smelting in China

Furthermore, crops in heavily polluted sites contain about 50-fold higher heavy metal contents than control sites and significantly exceed maximum levels according to national standards (GB 2762-2005 China; Tables 5 and 6). Heavy metal intake from vegetables or rice exceeds

Table 5 Crop pollution by lead–zinc mining and smelting in China

Time	Place	Pollution source	Media type	Pollutants	Reference
2002	Hezhang, Guizhou	Smelting	Corn	Pb and Cd	Bi et al. 2006
2005	Chenzhou, Hunan	Ore-dressing	Rice, cereal and bean	Cd	Liu et al. 2005a, b
2005	Fenghuang, Hunan	Mining	Rice	Pb and As	Ji et al. 2008
2006	Shaoxing, Zhejiang	Mining	Vegetable	Cd, Pb and Zn	Li et al. 2006
2006	Lanping, Guangxi	Mining and smelting	Corn, vegetable and peanut	Pb and Cd	Wang et al. 2007
2006–2007	Lechang, Guangdong	Mining	Rice and vegetable	Cd and Pb	Yang et al. 2006; Yang et al. 2007b
2007	Huludao, Liaoning	Smelting	Vegetable	Pb and Cd	Zheng et al. 2007c
2007	Shaoguan, Guangdong	Mining	Rice and vegetable	Cd, Pb and Zn	Zhuang et al. 2009
2007	Lechang, Guangdong	Mining	Asparagus and bean	Pb and Cd	Zhu and Yang 2007
2007	northwest of Guizhou	Smelting	Corn and vegetable	Pb and Cd	Li et al. 2009
2008	Zhuzhou, Hunan	Smelting	Vegetable	Cd, Pb and Zn	Xu et al. 2008
2008	Tieling, Liaoning	Mining	Corn and rice	Pb and Cd	Wu et al. 2008
2008	Guangxi	Mining	Rice and vegetable	Pb	Liu et al. 2009
2008	Fenghuang, Hunan	Mining	Rice, corn and soybean	Pb	Li et al. 2008
2009	Nanjing, Jiangsu	Mining and smelting	Vegetable	Pb and Cd	Hu and Ding 2009; Hu and Cao 2009; Wang and Luo 2009

Table 6 Environmental quality standards for crop in China of GB 2762-2005/unit: mg/kg

Elements	Pb	Cd	As	Hg
Maximum level	0.2	0.2	0.15	0.02

WHO standard criteria in some polluted areas. Potential solutions to these problems include adding apatite, slaked lime, and organic fertilizer to the polluted soils in order to reduce the mobility of heavy metals or choosing food crops that accumulate heavy metals at lower rates. Polluted crops are typically found in areas with polluted water and soil (Fig. 3), including the junction of Yunnan, Guizhou and Sichuan provinces, northern Guangxi province, west-central Hunan province, north of Liaoning province and north-central Zhejiang province.

Human health effects

Heavy metals are natural constituents of the earth's crust. Because they cannot be degraded by micro-organisms or destroyed, they are instead enriched in, and bio-accumulated by, living organisms. In polluted areas, heavy metals can enter the body through air, food, and water and can cause long-term health effects. Lead/zinc mining and smelting in China have released large quantities of Pb, Zn, Cd, and other metals into the environment. As shown in Table 7, many reports have documented the direct and indirect health effects of multiple heavy meal pollutants. Lead and Cd are the prominent human health hazards associated with lead/zinc mining, with typical exposure leading to high blood lead levels in children as well as malacosteon, kidney damage, and relatively complex cancers. Locations of where the intense health effects occurring are clearly separate from those of water, soil, and crop pollution (Fig. 4). In addition to areas with rich lead/zinc resources and highly developed smelting operations such as Yunnan, Guizhou, Guangxi, Hunan, and Guangxi, health effects frequently occurred in Henan and Shaaxi, which have concentrations of lead/zinc smelting industries but less lead/zinc mining. For example, Jiyuan city in Henan province, which is considered a leading city of China, has three large-scale lead/zinc smelting corporations and many other small- and medium-sized plants.

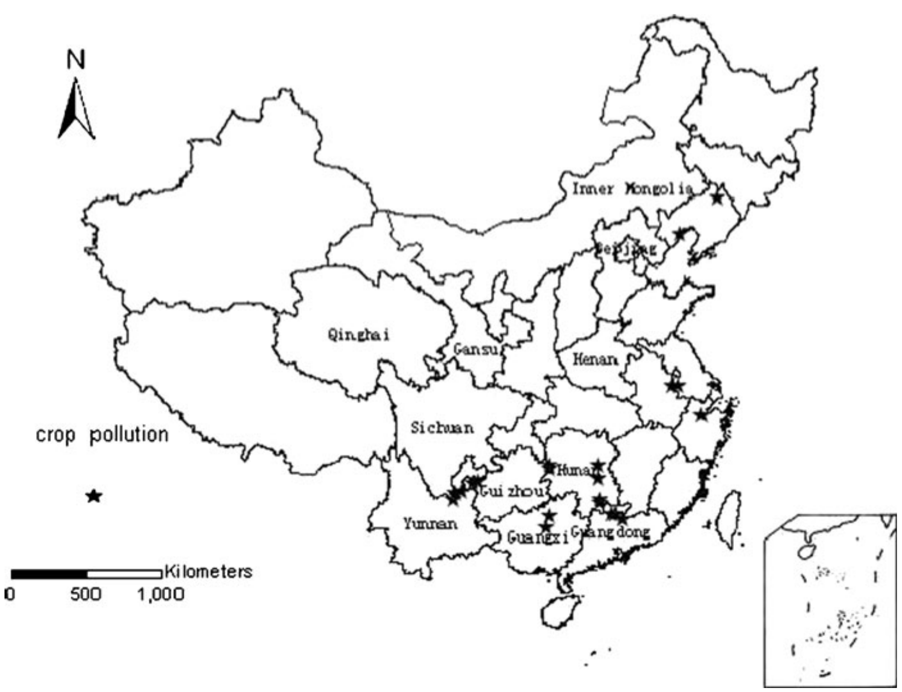

Fig. 3 Diagram of crop pollution due to lead–zinc mining and smelting in China

Table 7 Health hazard effects due to the lead–zinc mining and smelting activities in China

Time	Place	Route of exposure	Pollutants	Symptoms	Reference
2006	Guizhou	Water and food	Cd	Inhabitants suffered high Cd loads due to high Cd levels in food; some people suffered from malacosteon, bandy leg and hip valgus	Ye et al. 2006
2006	Zhuzhou, Hunan	Water, soil and crop	Cd	One death was attributed to Cd toxicity; unsafe Cd levels in urine were found in over 1000 villagers, and severe levels were found in about 200 villagers.	Caijing magzine, 2007, 24
2006	Huixian, Gansu	Soil, water, air and crop	Pb	More than 90% of the 300 studied children had unsafe blood lead levels; the maximum concentration was 619 μg/L; about 2000 villagers were poisoned by Pb	www.hsw.cn. 2006-09-05
2007	Hezhang, Guizhou	Soil water and crop	Cd	Cd levels in urine reached 28.16 μg/g, which was 8-fold higher than normal levels	Li et al. 2007c
2008	Hechi, Guangxi	Groundwater	As	136 villagers had unsafe levels of As in urine	www.chinanews.com 2008-10-08
2009	Qujiangxian, Shaoguan, Guangdong	Water, soil and crop	Pb, Cd, etc.	About ten villagers die annually from various cancers related to mining exploitation	Southern Metropolis Daily
2009	Fengxian, Shaaxi	Water, soil, air and crop	Pb	Lead levels in blood exceeded WHO standards in 615 to as many as 715 children; 163 children had middle-degree lead poisoning and 3 suffered severe-degree poisoning	2009-7-22
2009	Jiyuan, Henan	Water, soil and air	Pb	Children (younger than 14) in Kejing, Chengliu and ten other villages had blood lead levels above 250 μg/L; 1,008 children (32.4%) required emergency treatment	Economic Information Daily 2009-08-14 Southern Metropolis Weekly, 2009-11-30

Discussion

China has a long history of lead/zinc mining and smelting. As far back as the Ming Dynasty, the book *Shuyuan Miscellanies* by Lurong described details of silver–lead sulfide smelting technology. Because China's lead/zinc mineral resources are widely distributed and highly concentrated, they

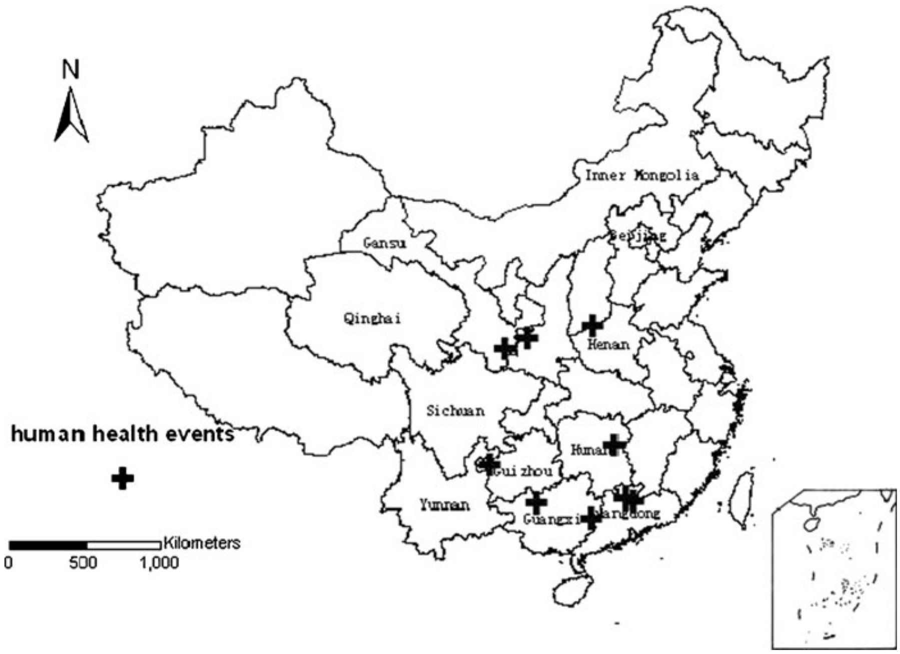

Fig. 4 Diagram of health hazard effects due to the lead–zinc mining and smelting activities in China

are favorable for industrial use. China's lead/zinc smelting industry has developed fast based on the rich resources and lower labor costs, and is mainly located in the areas of rich lead/zinc mineral resources (Table 8). China, as the world's largest producer and consumer of lead and zinc, has both created a serious resource shortage and released a large amount of heavy metals such as Pb, Zn, and Cd into the environment. The low efficiency of the lead/zinc mining industry has severely impacted the environment and has generated serious risks to human health. Clearly, environmental pollution and related health effects are concentrated in south-central and southwest China and the coastal areas of Liaoning, north of Henan, Zhejiang and Fujian. All of these areas have high population densities and developed economies and are located east of the Heihe–Tengchong line. Therefore, environmental protection departments and organizations should pay special attention to these areas.

Lower pollution levels exist in northwest and Inner Mongolia. Although these regions also have abundant lead/zinc resources and developed mining industries, their low population densities, dry climate, scarce rainfall, and alkaline soil help

Table 8 The distribution characteristics of the top 100 lead/zinc smelting industries and basic reserves in province or municipality of China

Province	Occupied numbers in the top 100 lead/zinc smelting industries of China	Ratio of lead + zinc basic reserves in China[a] (%)
Yunnan	16	31.01
Hunan	16	6.15
Henan	13	1.23
Guangxi	8	3.60
Anhui	7	0.38
Sichuan	5	5.22
Shaanxi	5	1.51
Guizhou	5	0.37
Guangdong	3	6.18
Liaoning	3	1.02
Inner Mongolia	3	17.00
Jiangsu	3	0.95
Shanghai	3	0.00
Gansu	2	10.18
Shandong	2	0.17
Zhejiang	1	2.04
Hebei	1	3.01
Shanxi	1	0.05
Hubei	1	0.04
Ningxia	1	0.00
Tianjin	1	0.00

[a]Date from China statistical yearbook, 2008

to inhibit the activation and migration of heavy metals. However, the seriousness of the problem may be underestimated due to limited economic development, cultural factors, and minimal awareness of environmental protection. In particular, distant, inaccessible small mines and smelters may be associated with serious, undocumented pollution. Significant additional work is needed to establish appropriate preventive measures for the risks associated with heavy metals. Because lead/zinc mining industries expanded rapidly and intensively beginning in the late 1990s, the data sources used in this study are relevant for the actual timeframe of lead/zinc mining. Therefore, the environmental pollution and human health effects described in this paper reliably represent the actual situation due to the exploitation of lead/zinc resource in China, and provide reliable data to guide environment management and the protection of human health in areas currently or potentially polluted by lead/zinc exploiting activities.

Conclusion

Over the past 10 years (2000–2009), environmental and health effects related to the Chinese lead/zinc mining industry have been concentrated in areas with rich resources of lead and zinc and intensive smelting operations: the junction of Yunnan, Guizhou, and Sichuan provinces, west-central Hunan province, central Guangxi province, northern Guangdong, northwestern Henan province, the border between Shanxi and Gansu provinces, and the region of Liaoning province near Bohai. Most of the reviewed cases of water, soil, and crop pollution and human health risk were caused by Pb and Cd. Typical exposure symptoms for these metals are high lead levels in the blood of children, malacosteon, kidney damage, and relatively complex cancers. These effects are not only detrimental to human health but also lead to social problems such as conflicts and disputes between residents and mining companies. Lead/zinc mining-related issues in these fragile areas deserve additional attention.

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